EEDP-01-1
June 1985

Environmental Effects of Dredging Technical Notes

BIOMAGNIFICATION OF CONTAMINANTS IN AQUATIC FOOD WEBS AS A RESULT OF OPEN-WATER DISPOSAL OF DREDGED MATERIAL

PURPOSE: This note provides information regarding the potential extent of biomagnification (the tendency for contaminant concentrations in animal tissues to increase through successively higher trophic levels) of contaminants in aquatic food chains resulting from the open-water disposal of contaminated dredged material. The note also provides a technically sound perspective and offers general technical guidance on assessing the environmental importance of biomagnification in aquatic food chains as a result of open-water disposal of contaminated dredged material. It does not consider biomagnification in nonaquatic organisms.

BACKGROUND: Disposal of dredged material in open water is used extensively by the Corps of Engineers. Pesticides and pesticide residues, nutrients, organic wastes, heavy metals, and other contaminants entering waterways may associate strongly with particulate materials and eventually accumulate in the sediments. The presence of potentially toxic contaminants in some sediments has generated concern that dredging and open-water disposal of contaminated dredged material may cause the deterioration of the aquatic environment. It is felt that persistent chemical residues from the dredged material may accumulate within the tissues of aquatic plants and animals to levels that are in excess of the ambient concentrations in their environment. Most of these substances have no known biological function, and there is concern that some may accumulate to levels that could affect the growth, reproduction, or survival of the organism or its predators.

Although well documented in terrestrial ecosystems, the occurrence and extent of biomagnification in aquatic ecosystems is questionable and is the topic of considerable debate. In 1983, extensive independent literature reviews were prepared by the Corps of Engineers (Kay 1984) and the Environmental Protection Agency (Biddinger and Gloss 1984) to assess the magnitude of contaminant biomagnification in aquatic ecosystems. The Corps literature review was conducted as part of the Long-Term Effects of Dredging Operations (LEDO) Program.

There were some minor differences between the two reviews, but both reached very similar conclusions regarding biomagnification of contaminants in aquatic food webs. The findings of these literature reviews provide the basis of this Technical Note on biomagnification as a potential contaminant mobility problem originating from the open-water disposal of contaminated dredged

:xperiment Station, Environmental Laboratory
sburg, Mississippi 39180-0631

material. The ecological consequences of any presumed biomagnification of contaminants are beyond the scope of this note. See Dillon (1984) for information regarding the consequences of contaminant accumulation in aquatic animals.

ADDITIONAL INFORMATION: Contact the author, Dr. Stratford H. Kay, (601) 634-2387 (FTS 542-2387), or the acting EEDP Program Manager, Dr. Robert M. Engler, (601) 634-3624 (FTS 542-3624).

The Phenomenon of Biomagnification

Many chemicals are present in the environment in extremely low concentrations, frequently near or below the levels readily detectable by routine analytical techniques. Living organisms may accumulate these chemicals to levels greatly in excess of the ambient concentrations in their environment. The ability to accumulate substances from the environment is biologically significant, for this is how living organisms obtain these substances commonly designated as "essential nutrients." However, nonessential chemicals (e.g. trace substances) also may be accumulated from the environment by natural biological processes. These substances have no known biological function and can accumulate to levels that may be detrimental to the organism.

Trace substances may enter living organisms in several ways. Both aquatic plants and animals accumulate trace substances by bioconcentration (direct adsorption and absorption from the sediments and water). Animals also accumulate trace substances by ingestion. The total process of accumulating substances by both ingestion and bioconcentration is called bioaccumulation. Occasionally, the concentrations of trace substances in living organisms continue to increase as the substances are passed on from lower to higher trophic levels. This phenomenon is called biomagnification.

The relative importance of food and bioconcentration as pathways for entrance of trace contaminants into aquatic organisms is the subject of considerable debate. The predominant route of entrance of a contaminant into a living organism depends on the nature of the environment inself and the relative level of exposure in the food and the external environment. Food becomes the primary source for contaminant accumulation only when bioconcentration from the external environment is minimal. Food-chain biomagnification as the result of dietary intake of contaminants is said to occur if the concentration of a substance increases at each successively higher trophic level as the result of dietary intake of food (prey) by a consumer (predator).

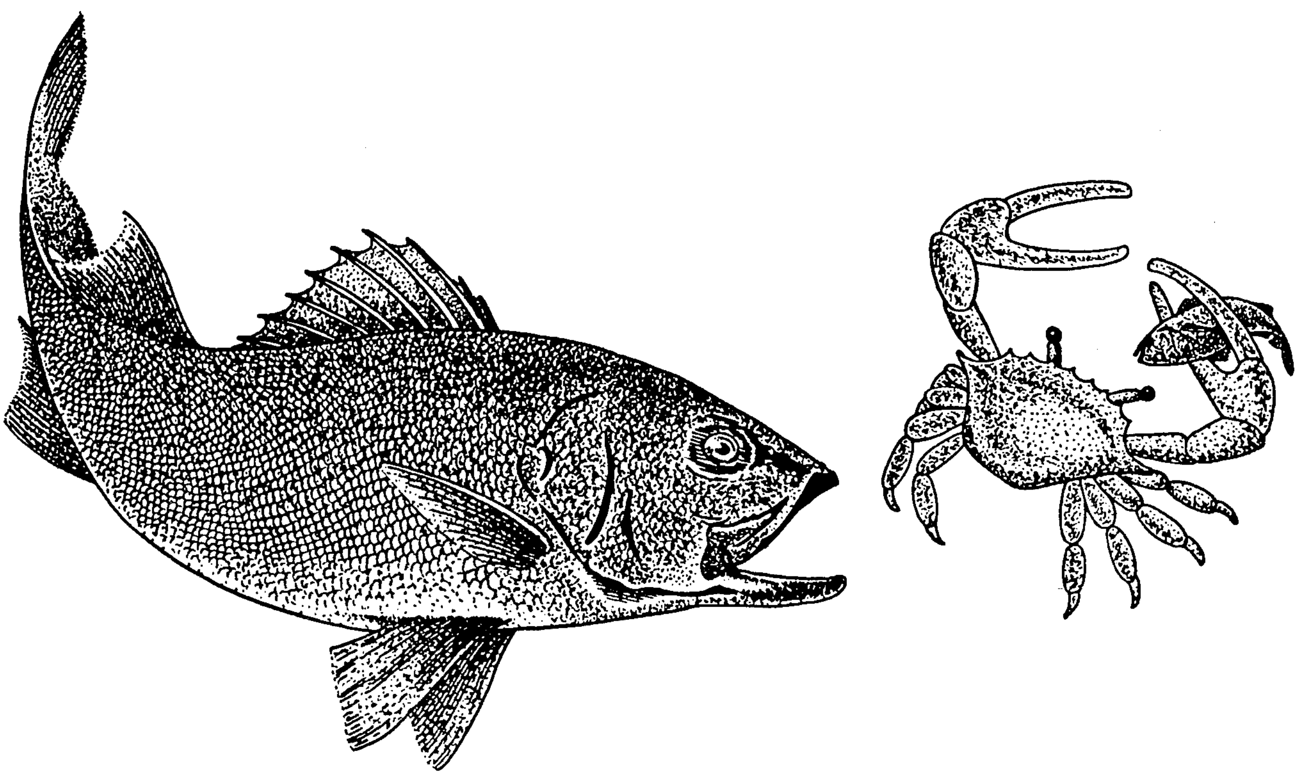
Biomagnification of contaminants may occur when all of the following conditions are met:

The chemical is persistent in biological systems (Macek 1970).

Direct uptake from the external medium in minimal.

The food pathway is essentially linear and highly structured, and the predominant energy flow is from lower to higher trophic levels.

Most aquatic (freshwater and marine) food webs are rather weakly structured, however, and do not have trophic levels as clearly defined as those of terrestrial systems. One species may occupy several trophic levels during its lifetime due to different feeding habits at different stages in its life cycle. Opportunistic omnivores also feed upon organisms occupying several trophic levels. Energy flow in aquatic food webs is multidirectional (for example, crabs are both prey and scavengers of fish), and a large component of the energy in aquatic systems is bound within the detritus.



Aquatic systems also rarely meet the criterion of minimal uptake from the external medium. Contaminant levels in the water may be low, but are usually higher than levels found in the atmosphere. In comparison to terrestrial animals (terrestrial is extended to include all animals that breathe air via lungs; shorebirds and "aquatic" mammals are considered as a special case of

terrestrial animals living partially or wholly in water and are not covered herein), aquatic (water-breathing) animals have large respiratory areas in proportion to body size. The solubility of oxygen in water, especially seawater, is low. Therefore, ambient oxygen available for respiration is substantially less for most water-breathing aquatic animals than for their air-breathing counterparts. Large quantities of water must be passed over their gill surfaces to provide adequate oxygen for respiration, simultaneously increasing the uptake of other essential and nonessential substances from the surrounding medium. The body integuments (coverings) of aquatic animals, especially invertebrates, are usually more permeable than the integuments of terrestrial animals, allowing chemicals to pass readily into and from their tissues.

The combination of intimate physical contact with the external medium, due to relatively permeable body surfaces and respiration via gills, and a complexly interactive trophic web has led to the conclusion that trace contaminants probably do not increase nearly as much with trophic levels (i.e., biomagnify) in aquatic systems as in nonaquatic systems (Isaacs 1975). Thus diet generally is thought to be of minor importance as a source of most contaminants in the aquatic food web (Scura and Theilacker 1977; Macek, Petrocelli, and Sleight 1979; Narbonne 1979).

Summary of Findings of the Literature Reviews

Heavy metals

The majority of the data reviewed by Kay (1984) and Biddinger and Gloss (1984) indicated that most heavy metals except methylmercury do not biomagnify either in freshwater or marine food webs. A review of field and laboratory studies (Kay 1984) showed that food may be an important source for the bioaccumulation of toxic heavy metals, particularly those that are essential trace elements (copper, zinc, and selenium), but also some that have no known metabolic functions (chromium, arsenic, cadmium, mercury, and lead). These elements may be taken up from food, but do not biomagnify to any extent from one trophic level to the next within the food web. Concentrations of these elements generally were higher in the tissues of benthic herbivores and detritivores and, occasionally, planktivores than in the top-level carnivores.

In the case of methylmercury, laboratory evidence reviewed by Kay (1984) suggested that biomagnification would not occur, but was contradicted

by the majority of the field studies, which indicated biomagnification. Both the Corps and the EPA reviews found that methylmercury has an affinity for muscle and tissues and apparently is biomagnified through the trophic web to the top predators. Consequently, higher, although not necessarily harmful, concentrations of methylmercury frequently are found in the large commercially valuable fishes than in invertebrates. However, the magnitude of increase from low trophic levels to high is on the order of one to ten times, not tens or hundreds of thousands of times as may occur in nonaquatic food webs. There is no satisfactory explanation for the contradictory results of laboratory and field studies with respect to methylmercury biomagnification.

Kay (1984) noted that inorganic mercury does not appear to biomagnify in aquatic food webs. Biddinger and Gloss (1984) also indicated that selenium and zinc might biomagnify; Kay (1984) noted that food was an important source for both metals, but did not indicate biomagnification.

Organic compounds

Food chain studies indicate that diet may contribute to the body burdens of a number of chlorinated and nonchlorinated organic compounds present in aquatic animals. Kay (1984) concluded that those compounds which appear to have potential for biomagnification in aquatic food webs were the polychlorinated biphenyls (PCB), kepone and mirex, benzo[a]pyrene, and naphthalenes. Biddinger and Gloss (1984) agreed on PCBs and added DDT to the biomagnification list. Kay (1984) found no strong evidence for biomagnification of DDT in water-breathing animals. However, where biomagnification occurred, it produced concentrations on the order of one to ten times higher in the upper trophic levels than in the lower ones, in contrast to the tens or hundreds of thousands of times higher as has occurred in such nonaquatic food webs as those involving DDT in fish-eating birds (Kay 1984).

As in the case of the heavy metals, the data on these organic contaminants sometimes were contradictory. Although top predatory fishes often contained higher levels of specific contaminants than other members of the food web, the relationship between contaminant levels in the tissues and an organism's position in the food web was not clear. The apparent contradictory nature of the data may reflect a number of factors, including the mobility of the top predators, age and size differences, inadequate understanding of the feeding habits of different species, particularly with respect to the changing of feeding habits at different stages of the life cycle, imprecision in the

assignment of trophic levels, and inadequate sampling and analytical procedures.

The most obvious finding of both reviews was that few organic compounds appear to biomagnify; however, relatively little information was available regarding the behavior of many of the compounds in aquatic food webs. Consequently, any absolute statement regarding the occurrence of biomagnification of these contaminants must be reserved until further data are available.

Conclusions and Implications

The literature reviews were prepared independently, almost simultaneously, and covered a similar range of heavy metals and organic compounds, and reached similar conclusions. The information from the reviews was consistent with the findings of other investigators (Isaacs 1975; Scura and Theilacker 1977; Macek, Petrocelli, and Sleight 1979; Narbonne 1979).

The available information indicates that biomagnification of contaminants is not a dramatic phenomenon in marine and freshwater food webs. Without doubt, most heavy metals and organic compounds do not biomagnify substantially over several trophic levels in obligate aquatic food webs. Kay (1984) and Biddinger and Gloss (1984) agreed that those few contaminants that may have the potential to biomagnify definitely included methylmercury and PCBs; and that selenium, zinc, benzo[a]pyrene, DDT, naphthalenes, kepone, and mirex may possibly biomagnify. The apparent biomagnification of these contaminants in aquatic food webs usually is by small factors (1, 2, 3, 3, etc.) rather than by orders of magnitude (10, 100, 1000, etc.) from the lowest to highest trophic levels.

It is considered unlikely that dredging of contaminated sediment and immediate placement in an open-water disposal area would cause any significant long-term changes in the chemical characteristics of the sediments or substantially alter the bioavailability of the contaminants in the sediment. Contaminant uptake from sediments and mobility within the aquatic food chain should be similar regardless of whether those sediments were left undisturbed or were dredged and placed in an open-water disposal site. Therefore, based on existing literature, it appears unlikely that the open-water disposal of contaminated dredged material will cause any widespread ecological perturbations due to contaminant biomagnification in aquatic food webs. Further concern and expenditure for research on contaminant biomagnification originating

from open-water disposal of contaminated dredged material appears to be unjustified.

Further attention should be given to evaluating biomagnification in food webs that include both aquatic and nonaquatic components, which was beyond the scope of these reviews. When food webs have major components in both aquatic and nonaquatic environments, such as the case of birds feeding on fish, biomagnification by large factors is possible and deserves serious consideration and evaluation. Placement of contaminated dredged material in a wetland or upland environment could impact associated nonaquatic portions of food webs.

Literature Cited

Biddinger, G. R., and Gloss, S. P. 1984. "The Importance of Trophic Transfer in the Bioaccumulation of Chemical Contaminants in Aquatic Ecosystems," Residue Reviews, 91:103-145.

Dillon, T. M. 1984. "Biological Consequences of Bioaccumulation in Aquatic Animals," Technical Report D-84-2, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Isaacs, J. D. 1975. "Assessment of Man's Impact on Marine Biological Resources," Marine Pollution and Marine Waste Disposal, E. A. Pearson and E. de F. Frangipane, Editors, Pergamon Press, Elmsford, New York, pp. 329-340.

Kay, S. H. 1984. "Potential for Biomagnification of Contaminants within Marine and Freshwater Food Webs," Technical Report D-84-7, U.S. Army Engineer Waterways Experiment Station, Vicksburg, Mississippi.

Macek, K. J. 1970. "Biological Magnification of Pesticide Residues in Food Chains," The Biological Impact of Pesticides in the Environment, J. W. Gillett, Editor, Environmental Health Sciences Series No. 1, Oregon State University, Corvallis, Oregon, pp. 17-21.

Macek, K. J., Petrocelli, S. R., and Sleight, B. H., III. 1979. "Considerations in Assessing the Potential for, and Significance of, Biomagnification of Chemical Residues in Aquatic Food Chains," Aquatic Toxicology, L. L. Marking and R. A. Kimerle, Editors, ASTM STP 667, American Society for Testing and Materials, Philadelphia, pp. 251-268.

Narbonne, J. F. 1979. "Accumulation of Polychlorinated Biphenyl (Phenoclor DP6) by Estuarine Fish," Bulletin of Environmental Contamination and Toxicology 22:60-64.

Scura, E. D., and Theilacker, G. H. 1977. "Transfer of the Chlorinated Hydrocarbon PCB in a Laboratory Marine Food Chain," Marine Biology, 40:317-325.